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14. ABSTRACT

This presentation provides data for validation of a CFD study done on a VORTAB flow conditioner. Objectives include achievement of a full-developed turbulent velocity profile for pipe flow. Secondary flow will cause a flow meter to register unexpected results. VORTAB reduces straight run distance with a minimal pressure loss and minimal validation of the component. CFD simulations, using LH2, showed that the pipe with a VORTAB generated more vorticity at the exit than the pipe without a VORTAB.

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Project Themis: PIV Measurement of Elbow Flow through a Flow Conditioner

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PA#11932

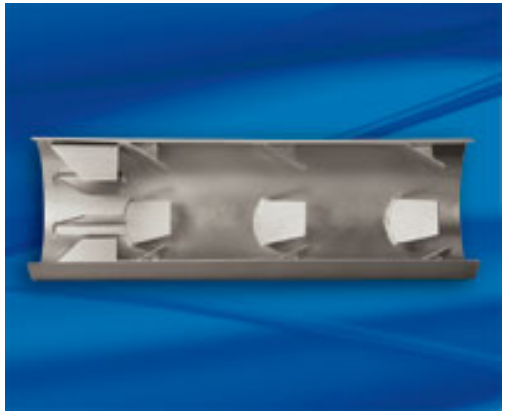
Profile

- B.S., Mechanical Engineering, May 2010, Virginia Tech
- M.S., Aerospace Engineering, UCLA
- Past Research Experience
  - NASA Ames Research Center
  - Army Research Laboratory
  - Virginia Tech Senior Design Project
- Future Work
  - Intern with SpaceX
  - Finish Masters Degree

Background

Research Objective:

- **Provide data for validation of a CFD study done on a VORTAB flow conditioner**



www.fluidcomponents.com

- Achieve a fully-developed turbulent velocity profile for pipe flow
- Secondary flow will cause a flow meter to register unexpected results
- VORTAB reduces straight run distance with a minimal pressure loss
- Minimal validation of component
- CFD simulations, using LH2, showed that the pipe with a Vortab generated more vorticity at the exit than the pipe without a Vortab.

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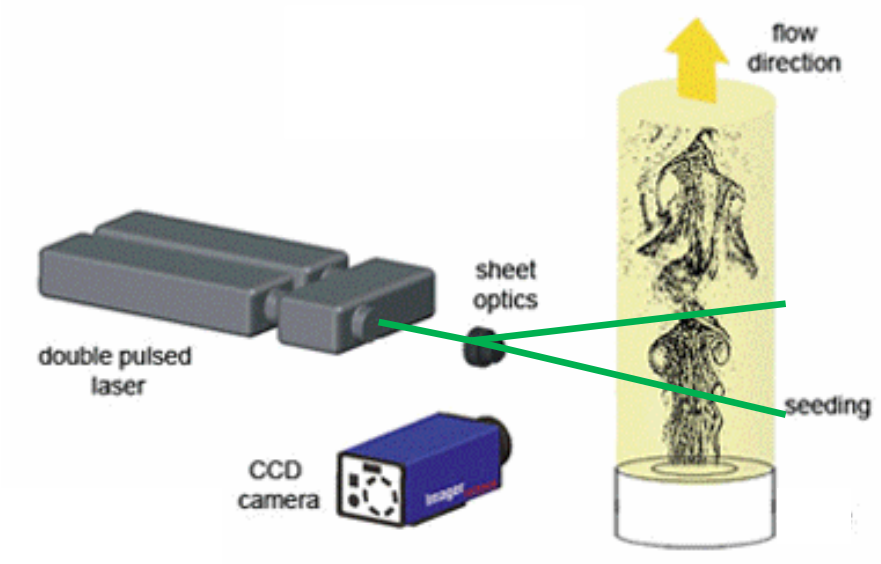
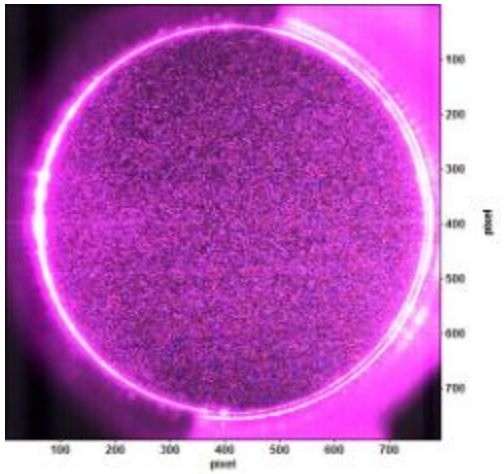
Particle Image Velocimetry (PIV)



www.LaVision.com

- PIV is an optical technique used to obtain instantaneous velocity measurements
- The main flow is seeded with particles
- Particles are illuminated using a laser and tracked to produce a vector field



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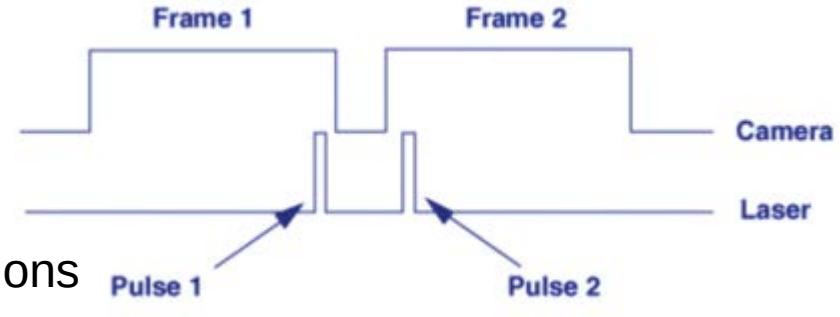
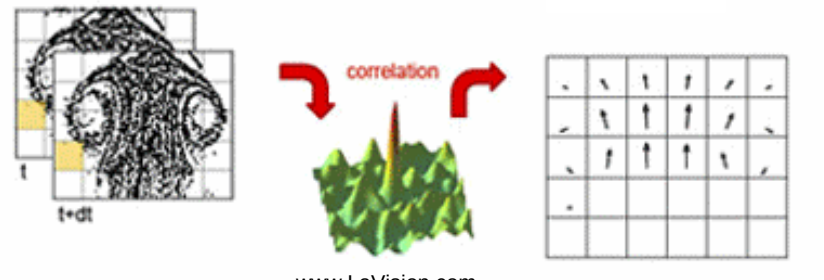
Particle Image Velocimetry (PIV)

- Frame-Straddling is a technique in which the lasers pulses on sequential frames

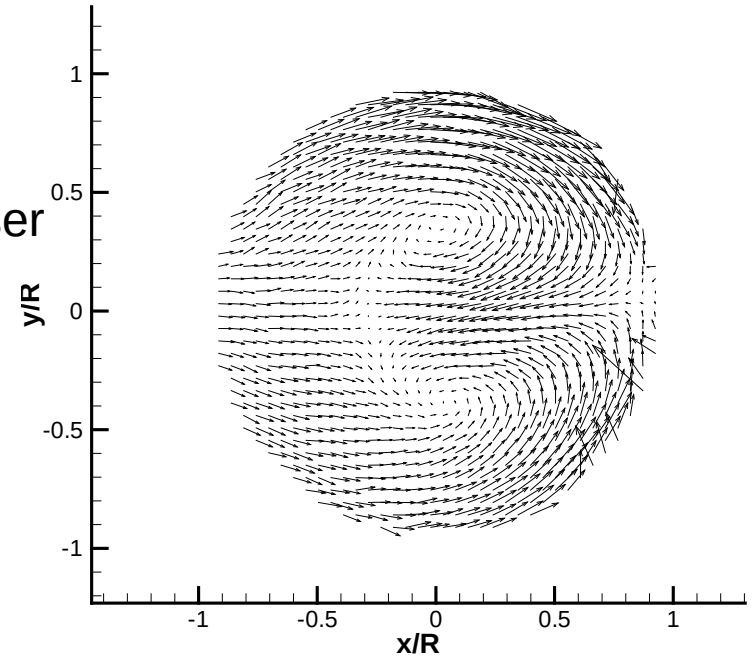


- Two image frames are split into correlation regions and compared

- A velocity is computed using the time between laser shots



www.LaVision.com



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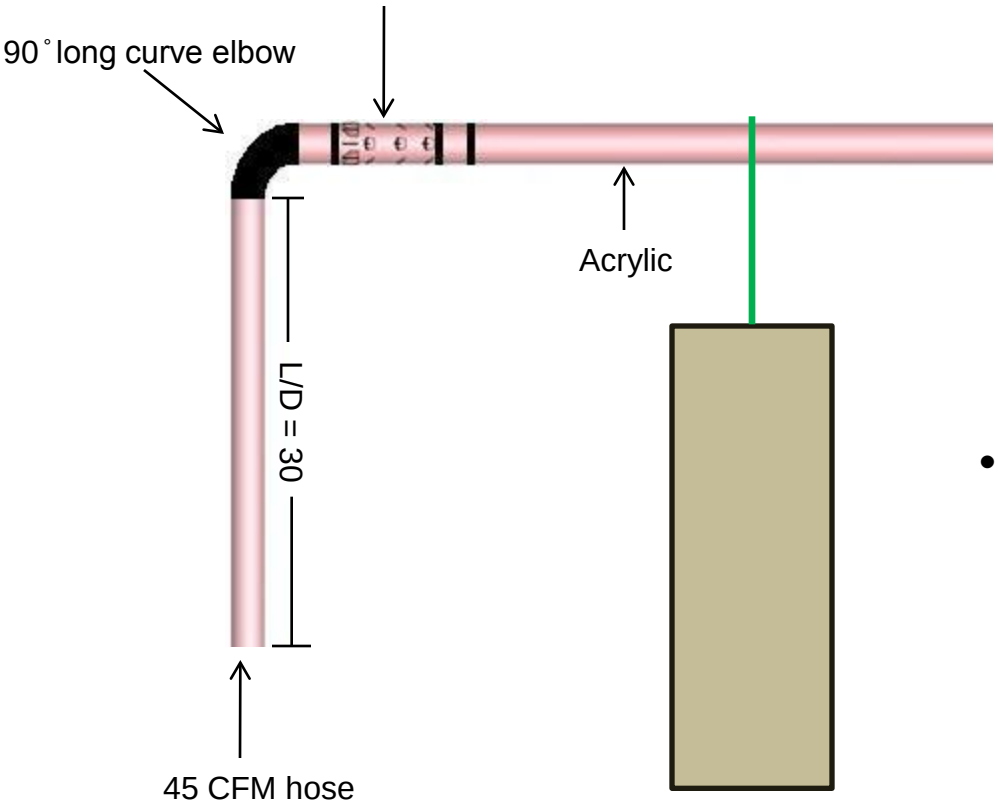
Test Facility

- VORTAB placed one diameter downstream of elbow



View

www.visionresearch.com

- Phantom V210
- 2,000 frames per second

- Litron LDY300
  - Dual Head Diode Pumped
  - Nd:YLF Laser
  - 527 nm wavelength
  - Max power = 20mJ @ 1kHz

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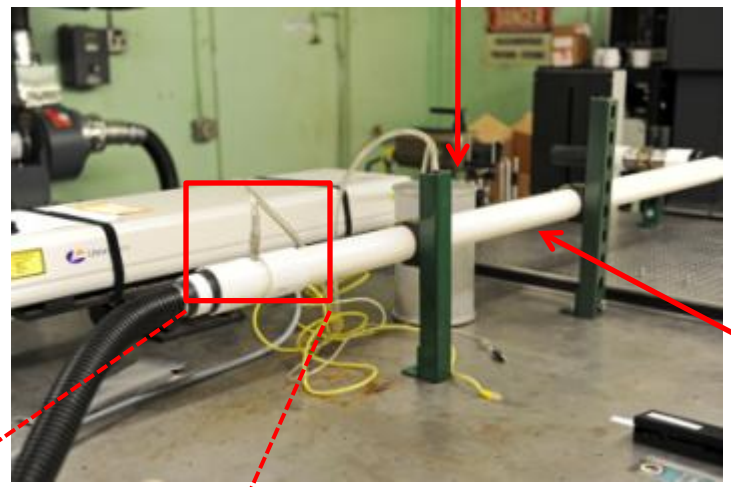
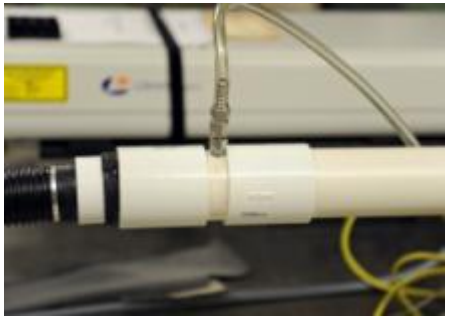
Experimental Setup

Laskin Nozzle

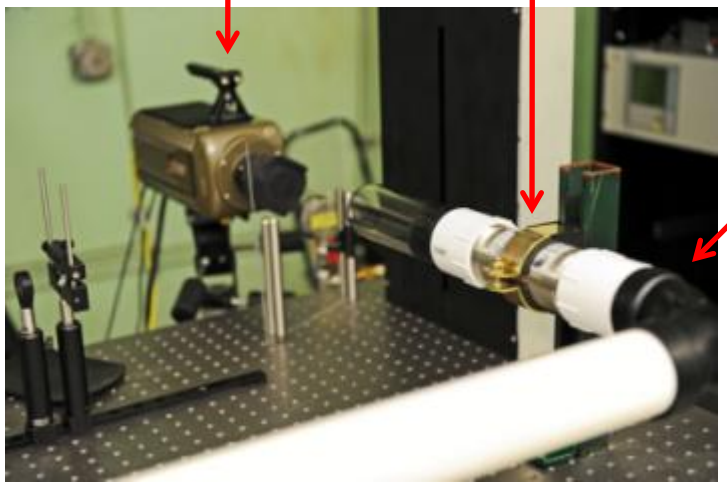


- Inner Diameter = 2”
- Mean Velocity = 9.63 m/s
- Reynolds Number = 32,000

PVC Pipe L/D = 30



Phantom V210 Camera VORTAB Flow Conditioner



90˚Long Curve Elbow

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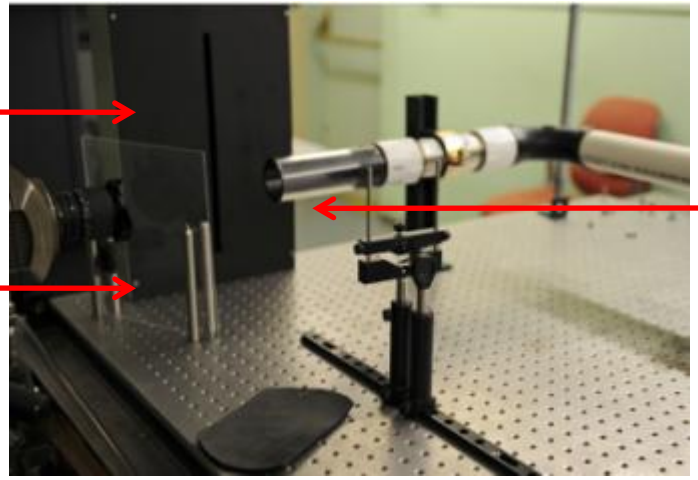
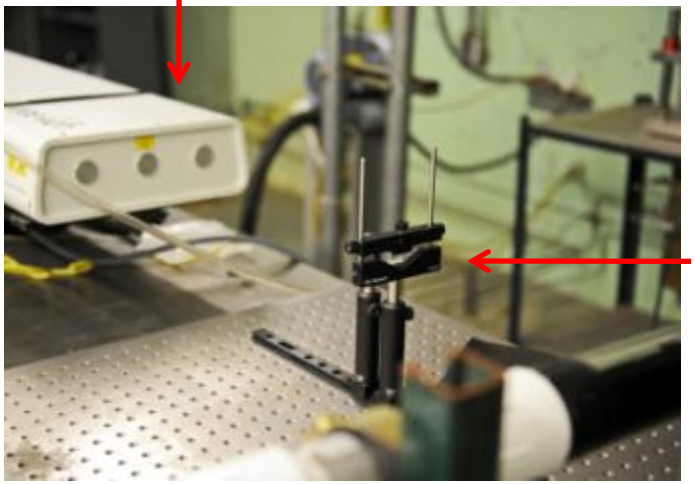
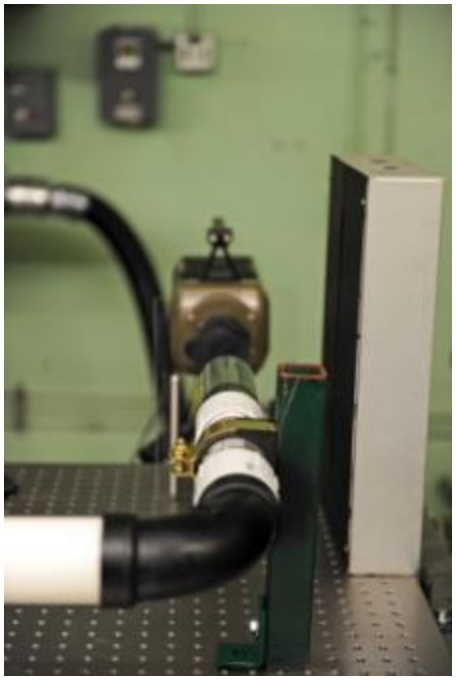
Experimental Setup



Litron LDY300 Series Laser





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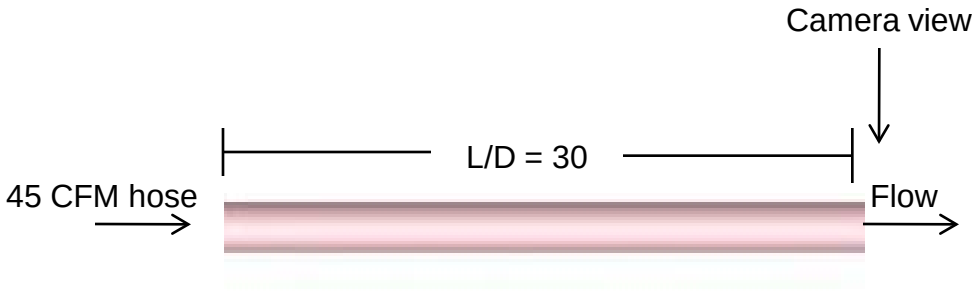
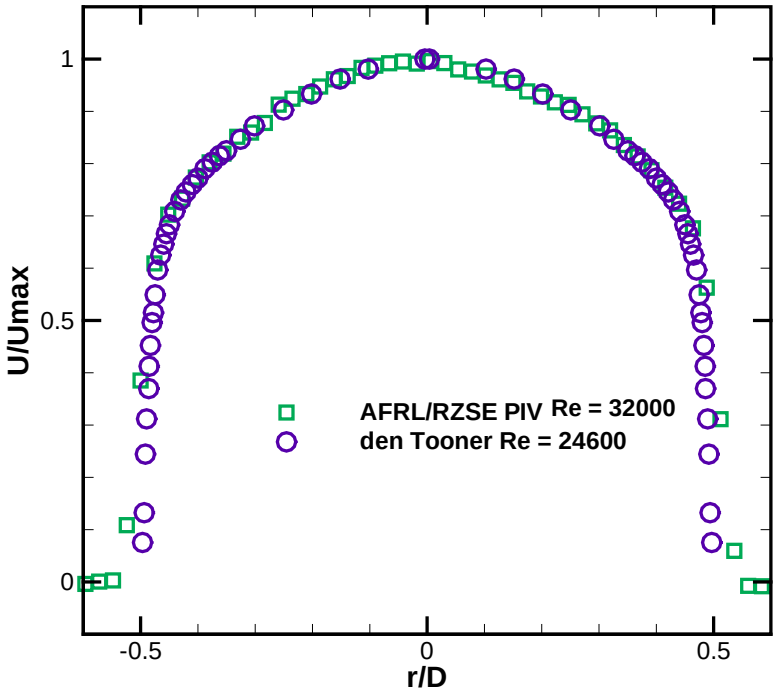
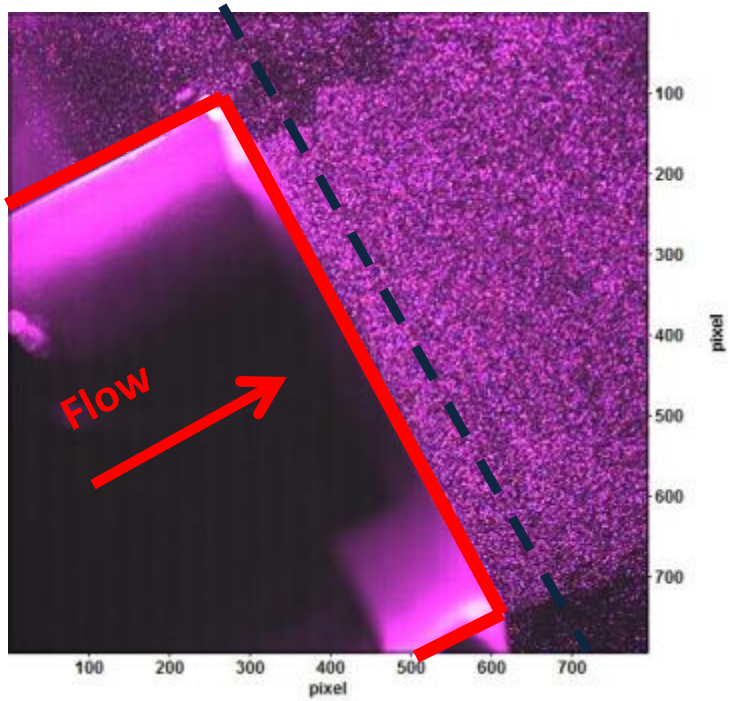
Initial Test Conditions



A fully developed pipe flow was found in the test section upstream of the elbow





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CFD Cases for Comparison

Reynolds number	Fluid	Vortab location	Comment
9,000,000	LH2	9D	USET installation
32,000	Air	9D	For Validation

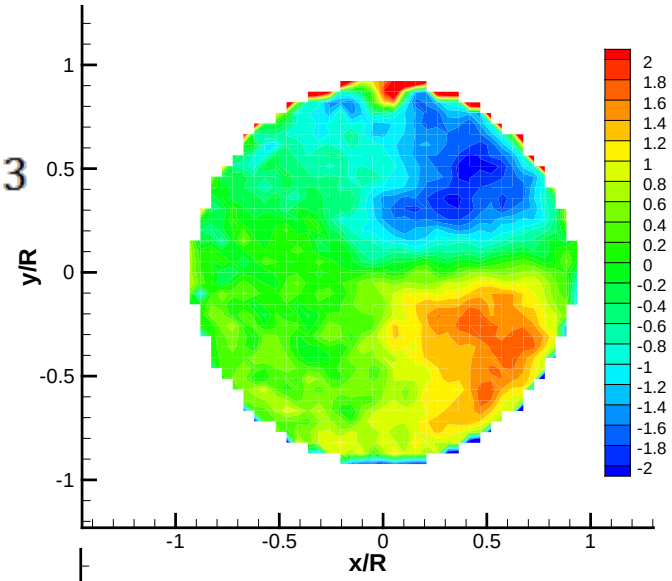
Additional details

- Fluent
- k-ε turbulence model
- Differences in geometry between the experimental and computational work:
  - Vortab location
  - Downstream contraction
  - Bend curvature
  - Vortab clocking

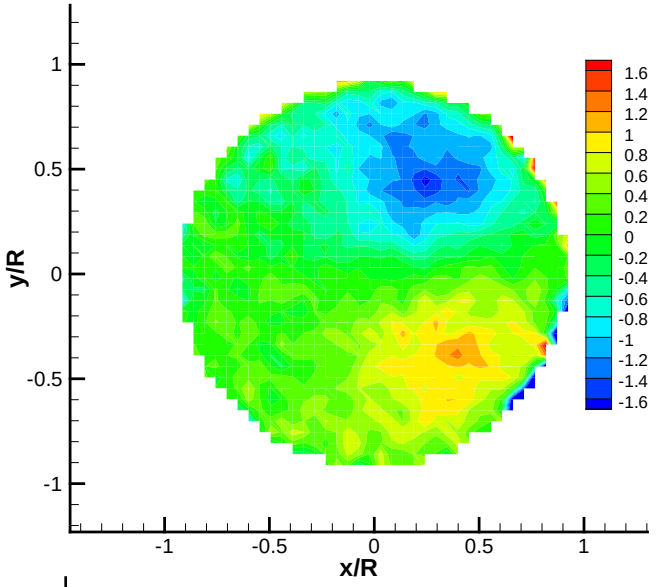
Nearfield Mean Vorticity Downstream of Elbow

$\frac{\omega}{U_\circ/D}$

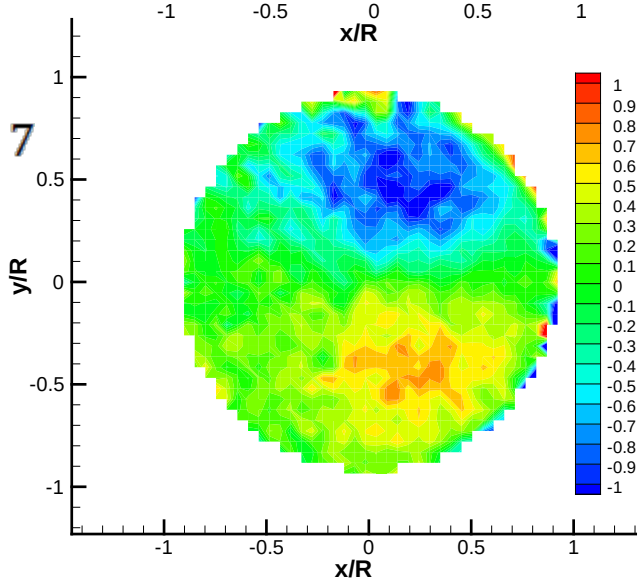
$\frac{X}{D} = 3$



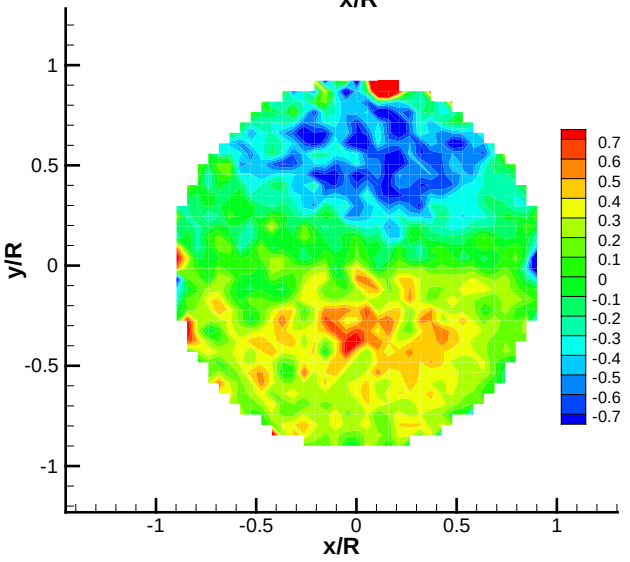
$\frac{X}{D} = 5$



$\frac{X}{D} = 7$



$\frac{X}{D} = 9$



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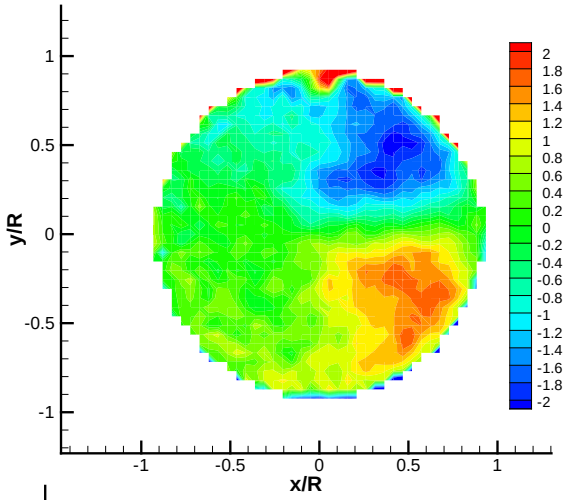
Nearfield Mean Vorticity Downstream of Elbow

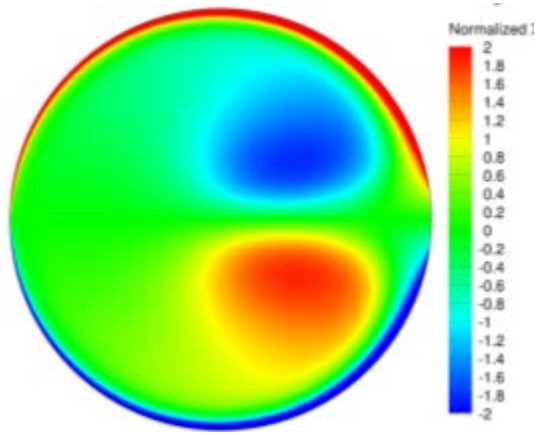
Experimental

CFD

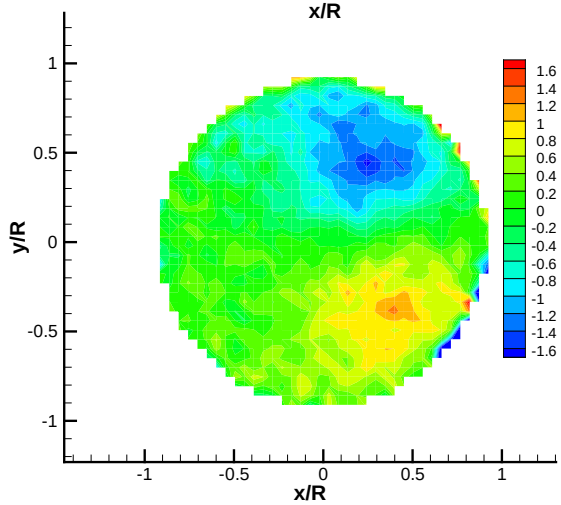
$$\frac{\omega}{U_\infty / D}$$

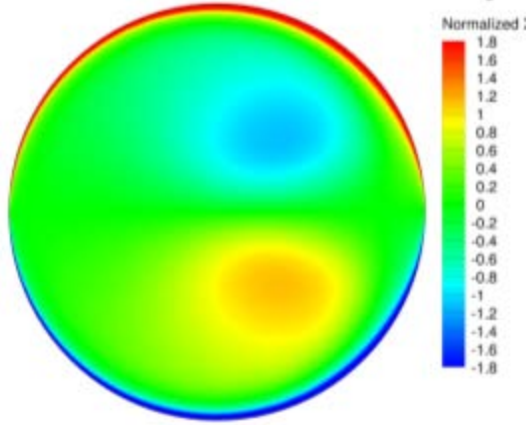
$\frac{X}{D} = 3$





$\frac{X}{D} = 5$





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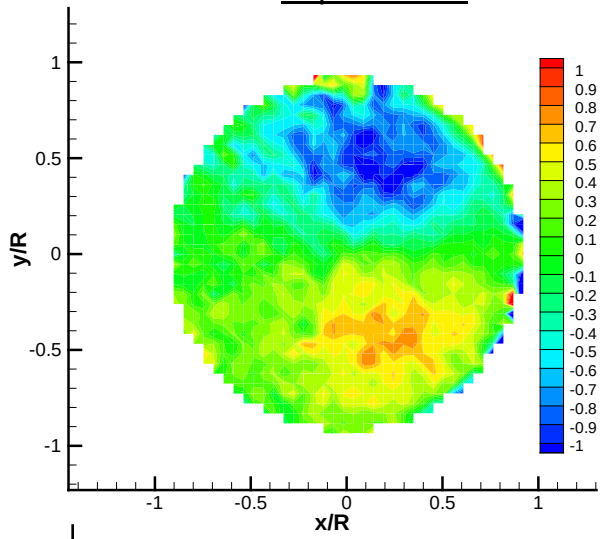
Nearfield Mean Vorticity Downstream of Elbow

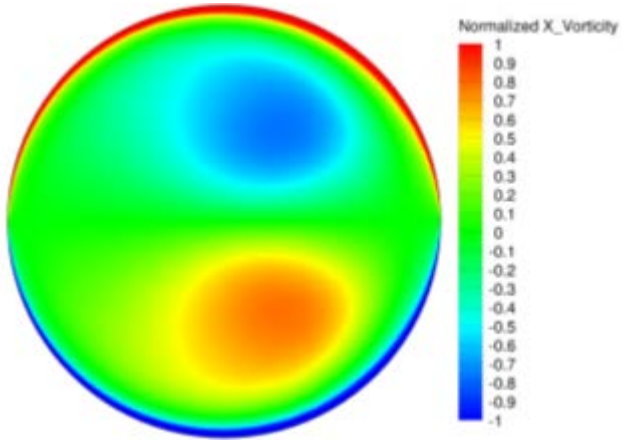
Experimental

CFD

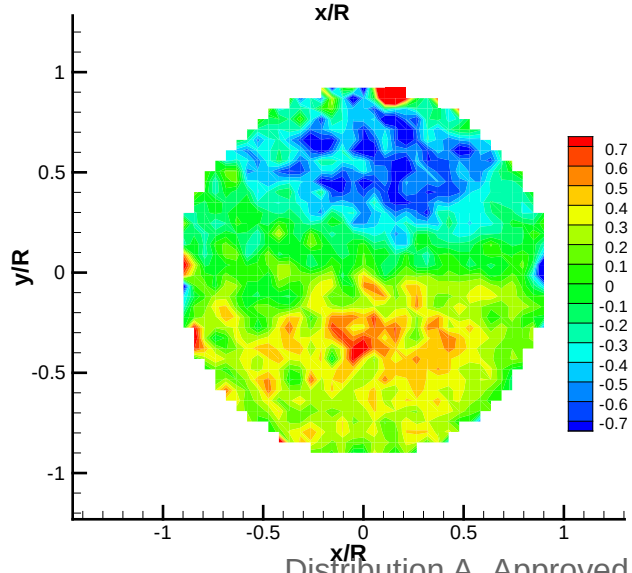
$$\frac{\omega}{U_\infty / D}$$

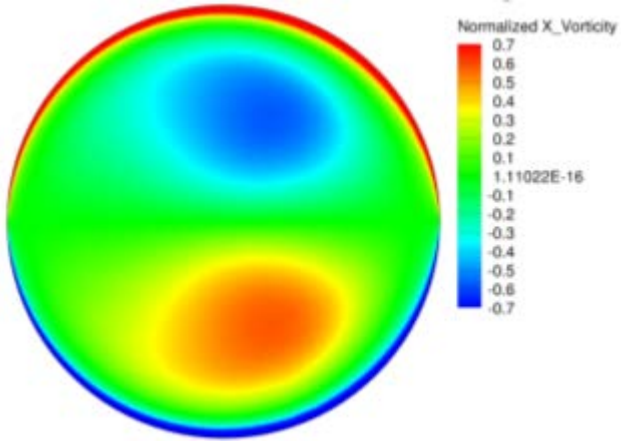
$\frac{X}{D} = 7$





$\frac{X}{D} = 9$





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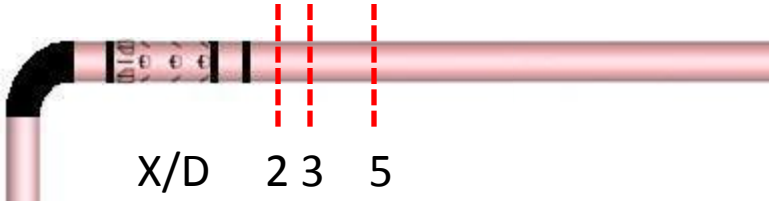
VORTAB Comparisons

- **Experiment for VORTAB at 1D downstream of elbow**

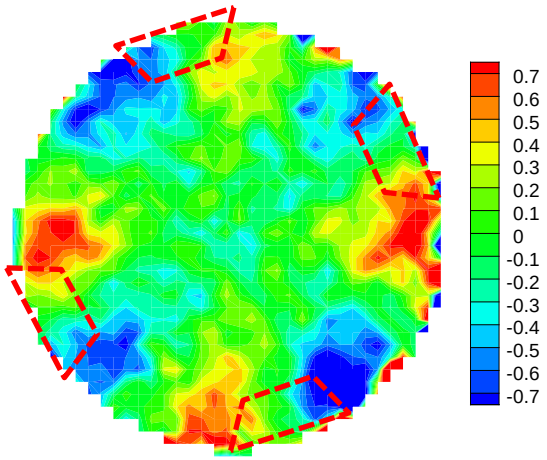


- **CFD for VORTAB at 9D downstream of elbow (USET installation) and with contraction**

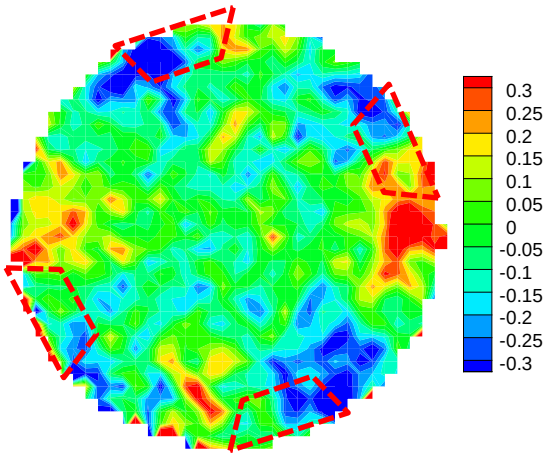
The experiment was unable to resolve the vorticity entering the vortab for the 9D installation location, therefore focus was placed on the effects of the vortab located closer to the elbow (i.e. 1D location).

Nearfield Mean Vorticity Downstream of VORTAB

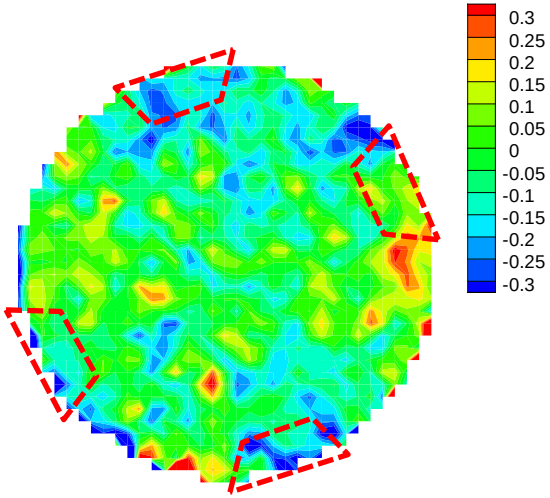
$X / D = 2$



$X / D = 3$



$X / D = 5$



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Mean Vorticity Downstream of VORTAB

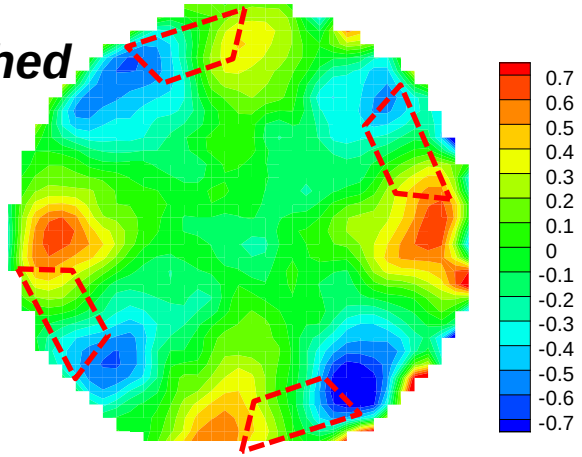
Experimental

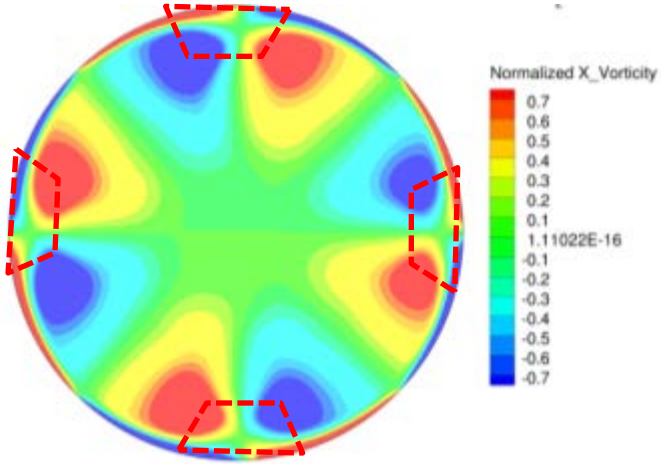
CFD

$$\frac{\omega}{U_\infty / D}$$

smoothed

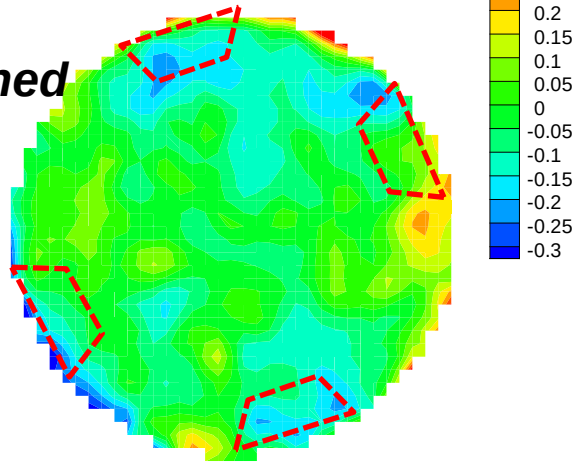
$X / D = 2$

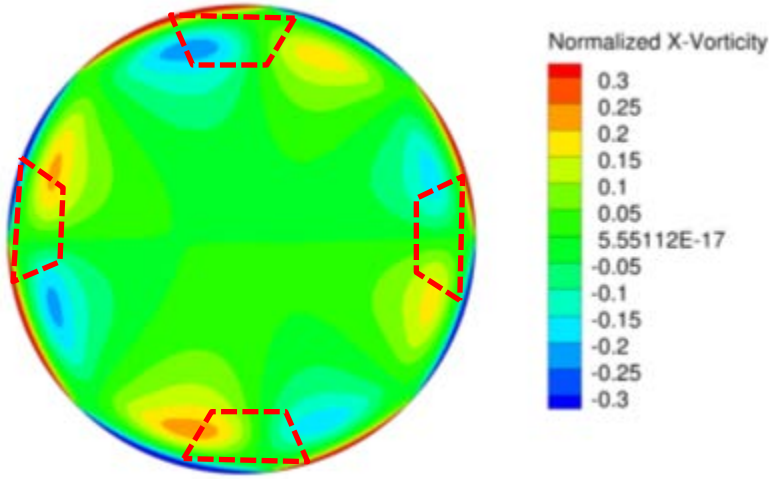




smoothed

$X / D = 5$





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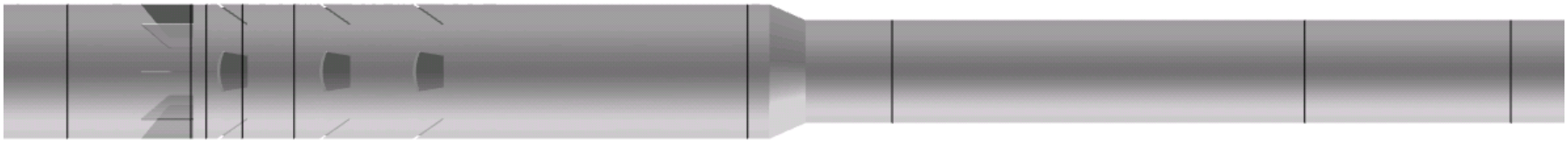
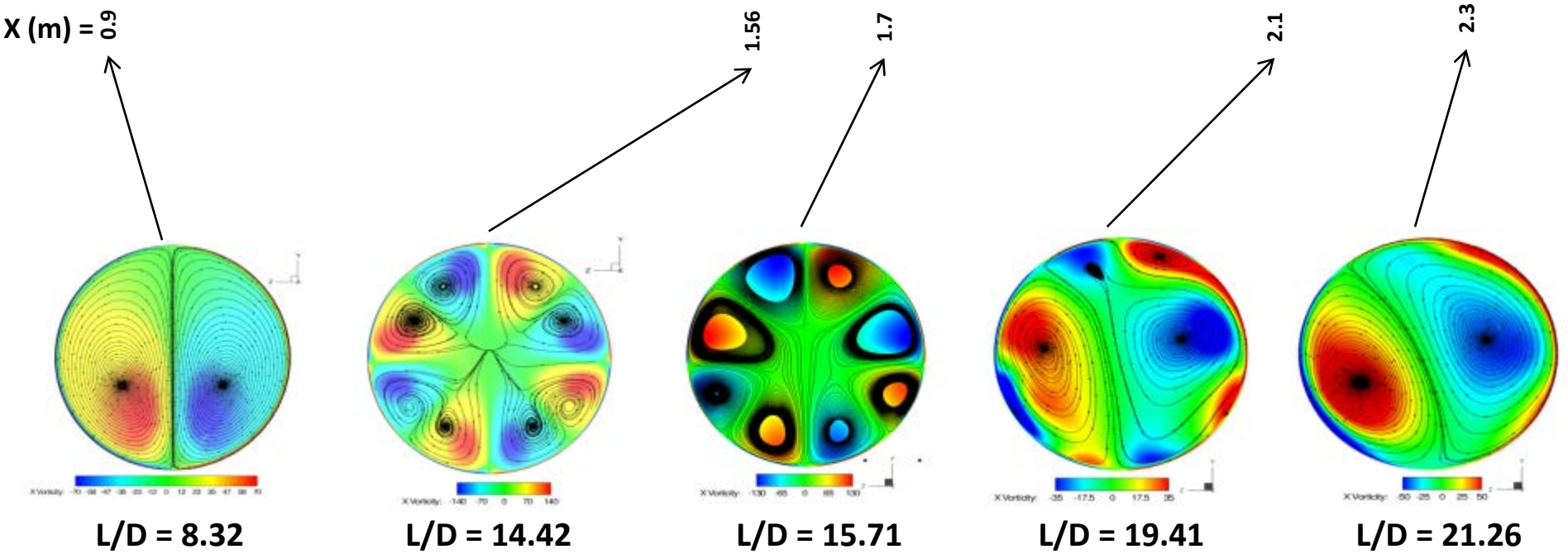
Vortex Dynamics at High Reynolds Number

Re = 9,000,000





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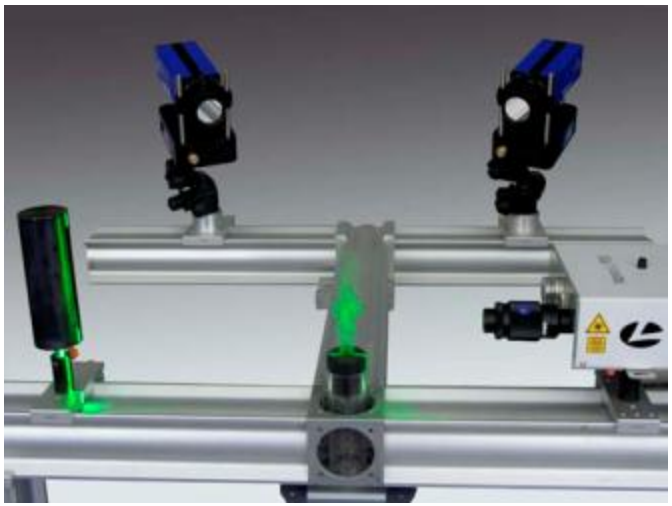
Conclusions

- Fully-developed turbulent pipe flow as initial condition
- Counter-rotating vortices were found at varying distances downstream of the elbow
- Experiment and CFD agree very well with and without the VORTAB installed
- VORTAB disrupts secondary flow for both configurations (experiment and CFD) at moderate Reynolds number
- New vortex dynamics emerge at high Reynolds number based on CFD simulations—unable to validate experimentally

Questions?

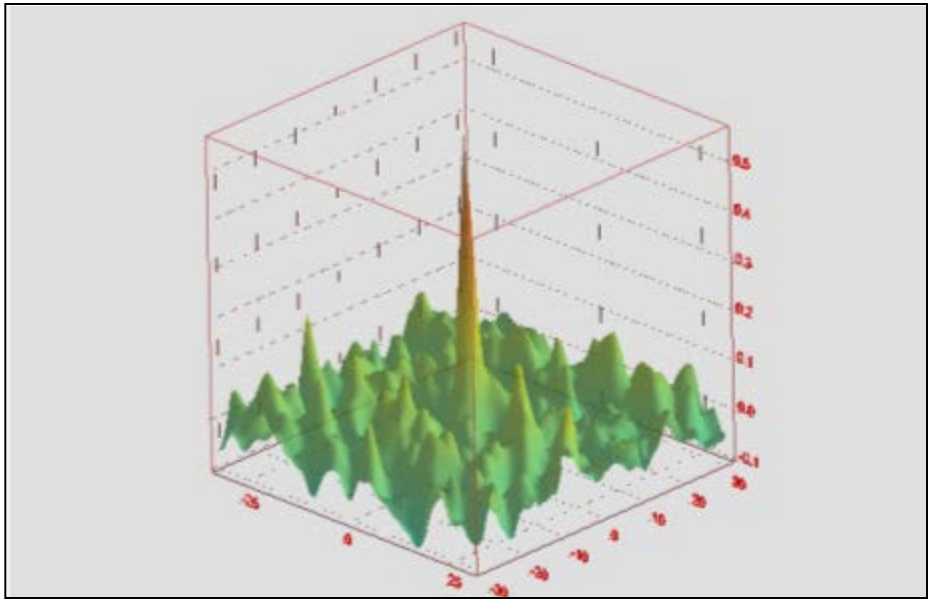
Recommendations

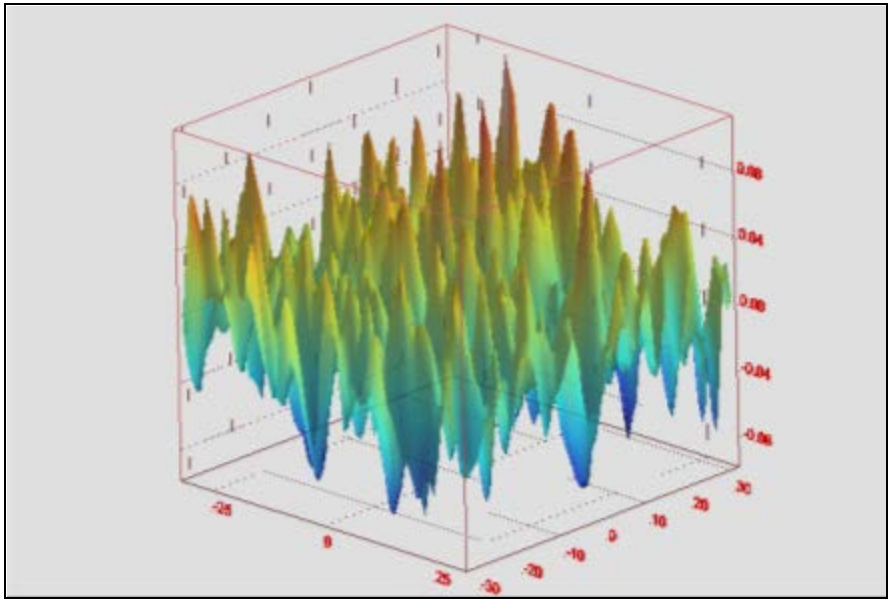
- Perform a CFD examination of experiment
- Test other flow conditioners
- Trouble resolving vorticity
  - Stereoscopic PIV



www.piv.de

Correlation Map





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Terminal Velocity

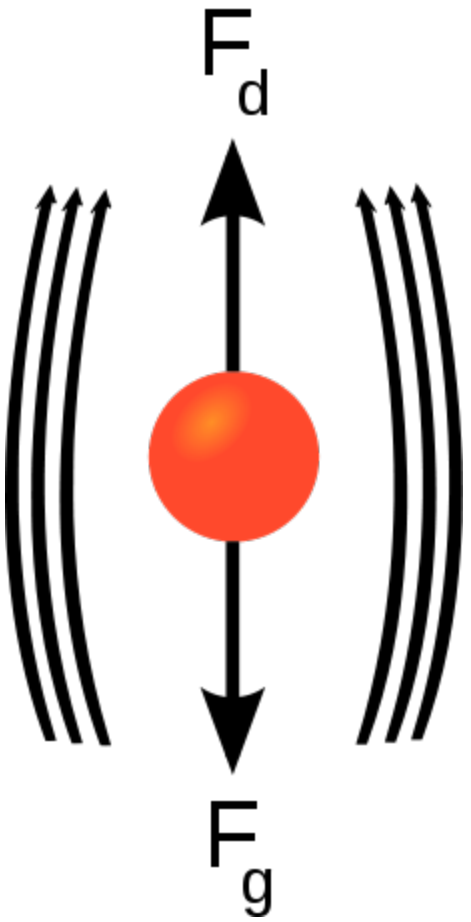
$$d = 1\ micron$$

$$V_t = \sqrt{\frac{2mg}{\rho A C_d}} = 5.27 \frac{mm}{s}$$

$$d_t = 15 * 10^{-6} sec$$

$$V_t * d_t = 7.91 * 10^{-5} mm$$

$$(7.91 * 10^{-5}) * 13.2 \frac{pix}{mm} = 0.00104\ pix$$



www.en.wikipedia.com

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